ENVIRONMENTAL LEAPFROGGING IN CHINA'S URBAN DEVELOPMENT? CURRENT STATUS AND OUTLOOK

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Abstract:

Cities in China will be crucial for deciding the direction of China's transition to a low-carbon economy and will play a key role in China's sustainable future. It is estimated that already over 170 cities in China have populations of over 1 million people, and the world's first mega-city, comprising Hong Kong, Shenzhen and Guangzhou, is home to about 120 million. Over the next two decades over 325 million people will migrate to the cities and by 2030 China's cities are expected to house about 1 billion people. To accommodate this large number of people, over the next two decades China will add some 40 billion square metres of floor space, which means doubling the existing floor space – adding the equivalent of ten cities the size of New York.

Will China's cities be able to 'leapfrog' conventional high-carbon development? Many cities in China have put forward low-carbon city development plans and China's National Development and Reform Commission has designated five provinces and eight cities as low-carbon development zones. The challenge will be on-the-ground implementation of these low-carbon development plans based on sound indicator systems for monitoring and evaluation of emissions reductions. The paper analyses two key sectors for urban development issues in Chinese cities, which are particularly relevant for the coming decade. The first is the application and use of renewable electricity technologies in Chinese cities as crucial element of low-carbon city development. Flexibility at the local level has allowed several cities in China to put forward support policies and targets for renewable energy technologies such as solar PV and geothermal heat pumps. Through the application of solar water heating technologies in particular, significant progress has been achieved, resulting in electricity savings in the building sector. Second, China's urban transport challenges include congestion and severe air pollution from vehicle emissions. The leapfrogging potential for urban vehicle electrification and interdependencies with renewable electricity technology are discussed. Over the last decade, the rapid emergence of electric two-wheelers has reduced urban air pollution, but other environmental impacts have occurred. Several cities have also initiated rollout programmes for electric cars, but the climate benefits of electric cars are questionable, given the current dominance of coal in China's electricity mix. The analysis concludes with an assessment of how these ongoing initiatives in Chinese cities may contribute to leapfrogging in urban environmental outcomes, particularly in terms of urban carbon emissions.

Keywords: China; low-carbon urban development; environmental leapfrogging

1. Introduction: Leapfrogging opportunities in China's urban development

China's rapid urbanization represents a major opportunity to reduce the carbon emissions of the world's largest carbon emitting country. The opportunity arises partly because China's cities are expanding rapidly, new residential developments are being constructed and new industries are being created for the first time. This offers potential for 'leapfrogging' defined as skipping stages of development and generations of technologies to avoid dirty stages of development and bypass environmental impacts (Goldemberg, 1998; Munasinghe, 1999). It is also an opportunity because psychological evidence suggests that, when people's circumstances change, they are more amenable to changing their habits (Maréchal, K. 2010). Moreover, it is clear empirically that in certain low-carbon technologies such as solar water heating, leapfrogging has been occurring in China (Schroeder, 2012). Local 'bottom-up' initiatives and strategies at the city level could enable fast low-carbon transitions (Bulkeley et al., 2011) or even leapfrogging of conventional high-carbon urban development. However, there are reasons for doubting that leapfrogging is easy across the energy technology spectrum, including in areas where technologies are not mature or still expensive, such as solar PV cells for urban application (Unruh and Carrillo-Hermosilla, 2006).

It remains unclear therefore how widespread leapfrogging may become in China, and whether the rapid growth and re-configuation of China's economy and cities will allow carbon emissions to be reduced at the rapid rates necessary if the world community as a whole is to achieve the 50% by 2050 target that many analysts consider essential in order to keep within the 2 degrees C guardrail (Rogelj et al., 2010; Richardson et al., 2009).

2. China's low-carbon city development plans

The concepts of a 'low carbon economy' and 'low carbon city' were introduced to China as recently as 2008 in the run-up to the Beijing Olympics. Since then the concepts have moved from being merely political slogans to concrete development approaches for Chinese cities. In 2010 China's National Development Reform Commission (NDRC) announced a programme for five low-carbon pilot provinces and eight low carbon pilot cities. The five provinces taking part in the pilot project are Guangdong, Liaoning, Hubei, Shaanxi and Yunnan; the eight cities are Tianjin, Chongqing, Shenzhen, Xiamen, Nanchang, Guiyang, Baoding and Hangzhou (see Figure 1).

Figure 1: China's Five Provinces and Eight Cities with low-carbon pilot programmes (source: Wang, 2011)

In addition, a large number of other Chinese cities have announced goals to become low-carbon cities. Of China's more than 600 major cities, more than 200 have adopted the goal of low-carbon development. Common elements of these local development plans are CO_2 emission intensity targets and energy consumption targets for buildings, transport or industry sectors for 2015 0r 2020. A selection of representative Chinese cities' low-carbon development plans is presented in Table A below.

Table A: Low-carbon development plans of selected Chinese cities (sources: Wang, 2011; The Climate Group, 2010; Chinese municipal government websites)

City	Date of announcement	Name of plan	Targets and actions
Baoding (Hebei Province)	December 2008	Baoding city people's Government views on building low-carbon city (also included in Baoding's 12th Five Year Plan)	By 2010, carbon intensity falls by more than 25% compared to 2005, with a goal of limiting CO_2 emissions per capita to no more than 3.5 tons; added value of new energy industry accounts for 18% of added value of industrial enterprises above designated size. By 2020, carbon intensity falls by more than 35% compared to 2010, with a goal of limiting CO_2 emissions per capita to no more than 5.5 tons; new energy industrial added value accounts for 25% of added value of industrial enterprises above designated size.
Chengdu (Sichuan Province)	January 2010	Program of work for building low carbon city of Chengdu	By 2015, carbon intensity falls to less than 1.15 tons per 10000 CNY; the city's non-fossil energy accounts for more than 30% of total energy consumption; forest cover increases to more than 38%.
Guangzhou (Guangdong Province)	October 2010	Guidance on low-carbon economic development (2011-2015),	Energy consumption per unit of GDP decreases to.54-0.56 tons of standard coal.
Guiyang (Guizhou Province)	July 2010	Guiyang City low carbon development Action Plan framework (2010 -2020)	By 2020, energy intensity per 10000 CNY is between 1.3-1.4 tce (40% below 2010 intensity). By 2020, carbon intensity falls from 3.77 tons per 10000 CNY in 2005 to between

			2.07-2.24.
Hangzhou (Zhejiang Province)	December 2009	Hangzhou Low-carbon city construction targets.	By 2020 CO_2 emission intensity per unit of GDP will decrease by 50 percent compared to 2005. Specific targets include the share of inner city trips undertaken by public transport will be over 50 percent and the number of bikes of the cities bike-share system will increase to 175,000 by 2020.
Hong Kong	September 2010	Hong Kong public consultation document on climate change strategy and action program	By 2020, carbon intensity falls from 0.29 tons/10000 CNY in 2005 to between 0.12-0.15 tons/10000 CNY, decreasing by 50-60% compared to 2005. By 2020, total carbon emissions decrease from 42 million tons to between 28- 34 million tons, decreasing by 19-33% compared to 2005. By 2020, CO2 emissions per capita reduce from 6.2 tons in 2005 to between 3.6-4.5 tons, decreasing by 27-42% compared to 2005.
Nanchang(J iangxi Province)	October 2010	Nanchang city pilot implementation program of national low-carbon city	By 2015, carbon intensity falls by 38% compared to 2005, non-fossil energy accounts for 7% of primary energy consumption, forest cover reaches 25%, growing stock volume reaches 3.8 million m^3. By 2020, carbon intensity decreases by 45-48% compared to 2005, non-fossil energy accounts for 15% of primary energy consumption, forest cover reaches 28%,

			growing stock volume reaches 4.2 million m^3.
Shenzhen (Guangdong Province)	January 2010	Shenzhen Medium to Long term Low-carbon Development Plan (2011 – 2020)	By 2015 Shenzhen's energy consumption per unit of GDP decreases by 19.5 percent compared to 2010.
Tianjin Municipality	March 2010	Tianjin climate change program	By 2010, carbon intensity is 2.0 tons/10000 CNY, energy intensity decreases to 0.85 tce/10000 CNY, 23.2% less than that of 2005; forest cover reaches 21%. By 2015, carbon intensity is 1.69 ton/10000 CNY, 15.5% less than that of 2010; energy intensity falls by about 15% compared to 2010; forest cover reaches more than 23%. By 2010, industrial CO_2 emissions controlled at the same level as 2007, emissions from agriculture are lower than that of 2008.
Wuxi (Jiangsu Province) .	March 2010	Low-carbon economic development planning of Wuxi	Industry: carbon intensity falls by 45% compared to 2005, renewable energy consumption rate reaches 20%. Transport: urban transit ridership increases from 22% to 32%. Building energy consumption decreases by 45% compared to 2005, 100% of new buildings meet 65% energy saving rate standard.
Xiamen (Fujian Province)	March 2010	The overall planning framework for low-carbon city of Xiamen	By 2020, the GDP of Xiamen is 7.14 times that of 2005, energy intensity decreases by 60% compared to 2005, total CO_2 emissions are limited to 68.64 million tons.

			By 2020, CO2 emissions from transportation, residential buildings, public buildings and production fields are respectively 12.4 million tons, 6.5 million tons, 12.7 million tons and 30.2 million tons.

In December 2011, the China Low-carbon Economy Media Federation, in cooperation with the State Council Research Institute, published a nationwide assessment and ranking of major Chinese cities regarding their low-carbon development (CLEMF, 2011). The ten leading low-carbon cities, ranked on the basis of a set of 18 indicators, were, according to the report, Suzhou, Beijing, Tianjin, Yichun, Lhasa, Liaoyang, Yinchuan, Liupanshui, Xining and Chengde. The report also identified 89 cities which had not taken any action towards becoming low-carbon cities.

In the public debate about low-carbon cities, significant voices disapprove of the current promotion of cities as low-carbon. For example, Jiang Kejun, director at the National Energy Research Institute, publicly stated that no city in China is yet a low-carbon city, particularly not the ones ranking top in the surveys mentioned above (Chinadialogue, 2010). This is supported by a number of research studies, for example by the Global Carbon Project (Dhakal, 2009), which shows that the 35 largest cities in China represent less than one-fifth of China's population but produced about 40% of the nation’s GDP, consume 40% of the total commercial energy of the nation and emit CO_2 at similar levels. The wide disparity between these cities and the rest of the country in per capita GDP, per capita energy consumption, and per capita CO_2 emissions shows the influence of large cities in shaping national energy and carbon profiles.

To make more transparent whether cities are indeed “low-carbon”, quantitative indexes are being developed to assess action and progress towards the low-carbon goal (Su et al., 2012; Zhu, 2011). However, although developed with great detail, these indicator sets do not adequately reflect the current status of the cities. For example, the indicator system of Su et al. (2012) consists of 16 indicators for assessing levels of low-carbon urban development. A comparison of 12 cities applying this indicator set ranks Shenzhen, Beijing and Guangzhou first, second and third.

One of the main reasons for the high ranking of cities like Beijing or Tianjin as being “low-carbon” is the use of aggregated data of energy use or CO_2 emissions per unit of GDP or per capita. Major cities rank highly in terms of being “low carbon” using metrics that give more weight to energy intensity (CO_2/GDP), but rank poorly if per capita emissions are taken as an indicator; in 2008 Beijing had 8.7 tCO_2 /person, Tianjin 10.8 tCO_2/person, Shanghai 11.9 tCO2/person (Price et al., 2011)

Indicator sets are clearer if adjusted for population, but those with a strong weight on GDP or GDP growth are not particularly meaningful measurements of whether a city or province is “low carbon”. Price et al. (2011) propose indicators based on energy end-use sectors (industry, residential, commercial, transport, electric power) for defining low carbon cities or provinces. For example, residential energy use per capita by city and province would be reported. This approach would also be useful for identification of concrete interventions for emissions reductions.

Given the limited development of international methodologies for accurately evaluating urban carbon emissions (Kennedy et al., 2009), it is not surprising that in China, also, robust methodologies for establishing carbon emissions inventories at the city level are not yet mature. Moreover, in line with China’s national carbon commitments to date, which are based on carbon intensity, only a few Chinese cities are currently targeting absolute carbon emissions as opposed to carbon (or energy) intensity (The Climate Group, 2010). One further problem is that the surveys only compare Chinese cities amongst each other, not internationally.

In the remainder of this paper two key end-use sectors, renewable electricity and transport, and the recent experiences of several cities are described. Based on this desk review of English publications and original Chinese language sources, including municipal policies and low-carbon development plans, both successful and unsuccessful approaches are identified and analysed.

3. Renewable energy in Chinese cities

One indicator which is important for determining whether a city is low-carbon or not, is the share of renewable energy in the city’s energy generation and use. Renewable energy generation technologies and energy saving technologies such as solar water heating (SWH) will play an important role in the low-carbon transition of China’s cities. In this regard, some Chinese cities have already demonstrated significant achievements, outlined below.

3.1 Solar energy use in Rizhao, Shandong Province

Probably the most cited example (e.g. Kwan, 2009; Wang et al., 2009) of Chinese city best practice in promotion renewable electricity and electricity saving technology is the prefecture-level city of Rizhao in Shandong province. Rizhao received international recognition as one of the winners of the World Clean Energy Award in 2007. The reason for this focus on Rizhao is that its municipal government has officially declared a goal to become carbon-neutral (Biello, 2008) and successfully started this transition through concrete actions. Rizhao used a combination of incentives and government funding for the city's solar industry to promote research and innovation. Legislative tools for integrating SWH into building codes and standards and educational campaigns further encouraged the uptake of renewables. These different policies helped lower the cost of a standard SWH (absorber area size 1.5 – 2 m^2) to below US$200, about the cost of an ordinary electric heater with a capacity of 1.5 – 2.5 kW. As a result, SWHs are now installed in 99 percent of all buildings in Rizhao’s urban area and in more than 30 percent of residences in its surrounding area.

With the utilization of solar energy in agriculture, construction, street lighting and heating, 3.8 billion kWh of electricity are estimated to be saved every year.[1] This shift to renewable electricity has already resulted in a halving of the city's CO_2 emissions. In addition, more than 15,000 residential units in Rizhao use biogas generated from agricultural waste water. The city capitalised on this development with policies to promote SWH take-up among the public. From 2001 to 2005, the economic growth rate for Rizhao averaged 15 percent per year – implying almost a doubling of income levels in only five years. All new buildings are required to include SWHs, and the municipal government oversees construction to ensure that this regulation is enforced and the panels are properly installed. The municipal government has run educational campaigns to encourage people to install solar in their homes, and some government bodies and businesses have provided free solar installations to their employees.

The data show that Rizhao is an example of a city leapfrogging ahead of other cities in terms of renewable electricity technology deployment and the development of renewables industries.

3.2 Solar water heater industry: Dezhou, Shandong Province

Possibly drawing on the positive experience of Rizhao, the provincial government of Shandong has set up an ongoing policy programme to support research and development in the solar industry and replicate the experience of Rizhao in other parts of the province. This has encouraged other cities in the province, such as Dezhou, with a population of 5.5 million people, to follow similar developments. Dezhou has already been named 'China's solar valley' (*zhong guo tai yang gu*). Similarly to Rizhao, SWH application is very advanced with coverage of about 80 percent of all buildings having SWH installations (Xu, 2010). Public street lighting is powered almost solely by solar PV. Moreover, solar energy is not only used in home application, but also in industries such as paper making, machinery and textiles.

[1] 3.8E9 kWh is 13.7 PJ.

Solar energy has also become an integral part of Dezhou's economy. The Himin Group, the world's largest SWH manufacturer, is based in Dezhou and has significantly contributed to the wide deployment of SWH throughout the city. Not only Himin, but around 100 other companies related to the solar PV and SWH industry value chains have developed in Dezhou and its economic development zone.

The Dezhou municipal government offers substantial support for the further development of the solar industry in Dezhou, including preferential tax benefits and other supporting policies. A variety of solar products are manufactured in Dezhou ranging from simple flat plate collectors to high end vacuum pipe collectors and high tech solar collectors. The local PV industry manufactures many products for different applications worldwide. Furthermore, company-led R&D is thriving in Dezhou, particularly in the building sector with many demonstration applications on how to integrate solar PV and SWH into building design. This has created an architecture and building design industry focusing on how to fit and integrate solar heaters and solar PV aesthetically into building design. An example is a new congress center constructed for the 4th World Solar Cities Conference in Dezhou in September 2010. The 75,000 m^2 center exhibits solar design and solar desalination technology, with an exterior area of PV panels of about 4,600 m^2 (Koerner 2009).

3.3 Renewable energy industry hub: Baoding, Hebei Province

Another example of a city which has made strong advances in promoting a renewable energy industry through creating city-level high tech renewable energy development zones is the city of Baoding, a city of about 10 million people in Hebei province, located approximately 140 km south of Beijing.. Renewable energy development zones are becoming an important mechanism within China’s innovation system as regional and local innovation clusters become significant forces in shaping China’s development. Analyses treating China’s economy as a monolithic entity often miss the nuances in how China innovates (Chen and Kenny, 2007). Local governments have been important contributors of investment in infrastructure and supporting institutions for new high-tech industry zones that have become incubation bases for new technology enterprise startups (Gu and Lundvall, 2006).

Baoding city has undergone an economic transition from relying on energy intensive automobile and textile industries into the fastest-growing national hub of wind, solar and biomass energy-equipment makers in China. Since 2002 the Baoding High-Tech Development Zone has had a particular focus on supporting the emerging renewable energy industry. In 2003 Baoding was designated as the main industrial base for development of China's new energy sector. Industries related to wind and solar electricity and energy efficiency are important in Baoding's economic structure. Baoding now has the highest economic growth rate of any city in Hebei Province, growing 11.0% in 2009. The renewables sector had gross industrial output of RMB 5.8 billion, up 25% from 2008 and accounting for 12.2% of the city's total (HKTDC, 2011)..

Baoding's economic shift was enabled by a combination of factors. Its growth as a hub for the renewable energy sector was supported by municipal government policies that included targeted tax benefits for companies and investors. Nearly 200 renewable energy companies have emerged in Baoding, some of which are now among China's biggest manufacturers in their fields. In the early period of the Chinese PV market from 2002-2007, PV products with a capacity of 436 MW were produced in Baoding. In 2006 the Baoding municipal government committed itself to the concept of Baoding as China's "Electricity Valley" (*Zhong guo dian gu*) and decided that the further development of renewables should be the nucleus of Baoding's further development. However, according to Reinvang et al. (2008), already by 2007 renewable energy industries in Baoding reported practical challenges related to access to and security of supply of necessary raw materials, lack of skilled personnel, scope for improvement in necessary public services, intellectual property, market access, and conditions for innovation. At a policy level, there seems to be a need for clearer long-term policy goals and improved framework conditions, particularly with regard to solar PV and wind. Whereas renewable energy featured prominently in the 11th Five Year Plan of Baoding for 2006-2010, in Baoding's new Five Year Plan (2011-2015) renewable energies are not specifically mentioned. Instead, the new plan calls for the development of a new low-carbon district in junction with the 'Electricity

Valley' with an allocated area of 20 km^2 (Baoding Municipal Government, 2011). The plan, however, so far lacks clearer details to guide implementation.

3.4 Solar capital: Kunming, Yunnan Province

Another city which aspires to become the "solar capital" of China is Kunming in Yunnan province, south-western China. In 2008, Kunming adopted a renewable energy policy framework, "Advice on renewable energy development and use", which called for 50% of all buildings in the city to have SWH and solar PV by 2010, a target likely to have been met. The framework also established a designated development zone within the city, with buildings there to reach a 70% share, and for new construction to reach a 90% share.

In 2012 the Kunming Municipal Government issued a detailed 12th Five-Year Plan, Solar Industry Development Plan (*Kun ming shi shi er wu tai yang neng chan ye fa zhan gui hua*).[2] It reinforces the previous targets and includes additional detailed targets for 2015, such as the proportion of new city buildings with SWH applications over 95% with a total collector area of solar water heaters of at least 12 million m^2. Solar PV applications on buildings in the city are to reach more than 70%. Industry targets include 200 MW of solar silicon production, a capacity of 3000 tons/year. The production of solar cells is to achieve a capacity of 500 MW/year by 2015. The solar energy industry output value is expected to be more than 20 billion CNY per year.

Support measures to promote renewable energy include low-interest loans, tax exemptions, and a special fund to encourage private investment from government source. The city has also incorporated solar investments into its own procurement. And the city is providing extended support for R&D, industry development, energy industry-related university education, and a SWH equipment testing center.

The plan also mentions a number of existing problems in Kunming's solar industry which include a need to enhance the technical capabilities of the more than 100 local small and medium sized solar companies, limited local and domestic

[2] 昆明市十二五太阳能产业发展规划 http://www.yndtjj.com/news/?15_17868_3.html

markets for solar products, lack of production capacities for related equipment such as controllers and inverters, dependence on polysilicon imports and skills shortage.

Outside the city, construction of the 166 MW Kunming Shilin solar PV power plant began in late 2008 and will become the largest such plant in China, at an investment cost of almost $1.5 billion. The first 20 MW phase of the construction was completed in May 2010; full completion will be achieved in 2015.

3.5 Geothermal heat pump applications: Shenyang, Liaoning Province

The city of Shenyang in Liaoning province, northern China, was chosen as China's geothermal heat pump (GHP) technology pilot promotion city in September 2006. The reason for this choice is the relatively rich geothermal potential in Liaoning Province. In response to being designated as pilot city, the Shenyang municipal government introduced guiding regulations and as a result Shenyang's GHP installations increased from 3.12 million m^2 of GHP-heated floor area in 2006 to 35.85 million m^2 in 2008 – about 18% of the total heating space area of the city, equivalent to a heating power capacity of 1,790 MW (Zheng, 2010). The city planed to increase GHP floor area to at least 65 million m^2 by the end of 2010. GHP will then account for 32.5% of the entire city's heat supply (The Climate Group, 2009). Local industry has developed at the same time. In 2005 there were only about one dozen GHP-related companies in Shenyang;, by 2007 there were more than 70 specialised companies (Zheng, 2010).

3.6 Capital city Beijing

The 2008 Beijing Olympic Games boosted renewable energy development with a number of new projects in the capital city, at a time when Beijing still received only 2% of its total energy consumption from renewables. The city had 3.8 million m^2 of SWH and 1.2 MW of grid-tied solar PV installed. There were also biogas digesters in use by 50,000 households, and 113 small hydro power plants. The 358 'Green Olympic' projects gave the development of renewable energy a boost, off a relatively low base, below the national average. This rather slow development does not constitute leapfrogging in energy development, but it suggests that the transition towards cleaner energy systems can be significantly advanced in a decadal time frame, if the right framework conditions are implemented.

Beijing's 11th Five-Year Plan (2006-2010) targeted a 4% share of electric power capacity by 2010, up from 1% in 2005, and a 6% share of heating capacity by 2010 from renewable energy sources including solar, biomass, geothermal wind and hydro. The targets were, however, not achieved and renewable energy accounted only for 3.2 percent of the city's final energy consumption in 2010 (see figure 2).

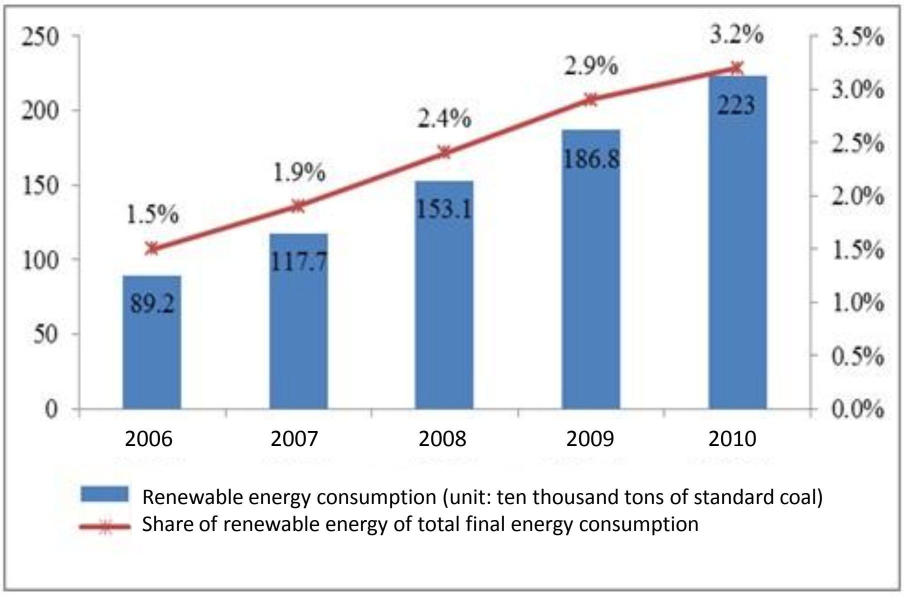

Figure 2: Achievements in renewable energy development under Beijing's 11th Five Year Plan (2006-2010) (Source: Beijing Development and Reform Commission, 2011)

The city allocated 13 billion CNY ($2 billion) over the five-year period. GHP received subsidies of 35 CNY/m^2 for water-source pumps and 50 CNY/m^2 for ground-source pumps. The city had more than 500 GHP projects underway by the end of 2007, using shallow ground geothermal units that cover the urban area and extend beyond the suburbs. Beijing enlarged the 2008 capacity of 10 million m^2 of heating capacity from water-source GHP facilities to 30 million m^2 by 2010, increasing annually at a rate of about 6 million m^2. The city offered a one-off subsidy of 35-55 CNY (US$ 5-8) per m^2 of floor area for heat supply projects using GHP (The Climate Group, 2009). The city has also been installing renewable electricity sources in municipal infrastructure, including 57,000 solar street lamps. The support for solar and geothermal put these two technologies ahead with the largest share of the renewable energy technologies used in Beijing (see figure 3).

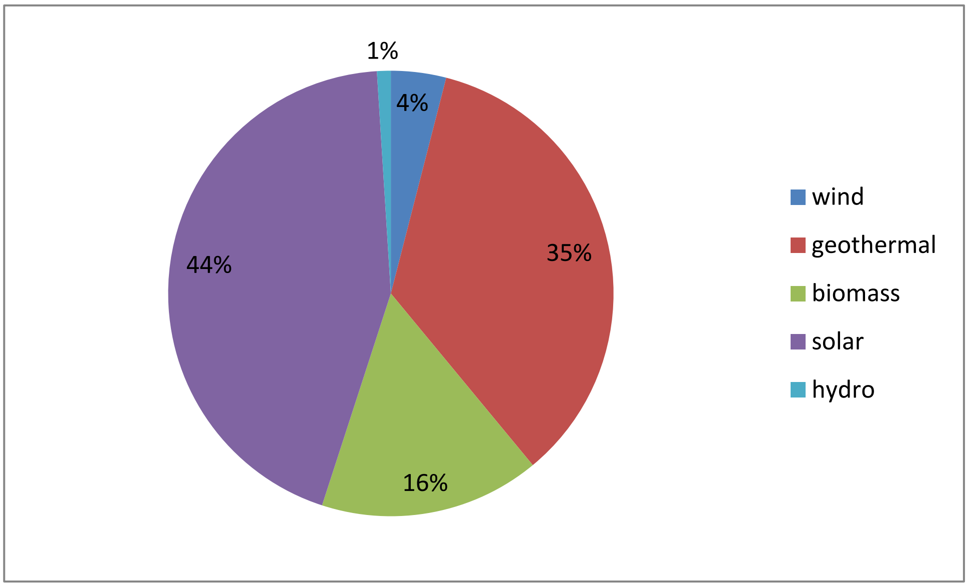

Figure 3: Types of different renewable energy technologies in use in Beijing end of 2010 (Source: Beijing Development and Reform Commission, 2011)

In October 2009 Beijing adopted an updated three-year solar development plan[3] which was implemented at the beginning of 2010. By late 2012, Beijing aims to have established seven million m^2 of SWH, 70 MW of solar power generation, solar manufacturing output with a value of 20 billion CNY, and the formation of testing centers for PV and solar thermal heating applications. As a medium term goal for

[3] Beijng Shi Jia Kuai Tai Yang Neng Kai Fa Li Yong Cu Jin chan Ye Fa Zhan Zhi Dao Yi Jian《北京市加快太阳能开发利用促进产业发展指导意见》 http://www.china5e.com/show.php?contentid=67188

2020 Beijing plans SWH to achieve installation of 11 million m^2, to install 300 MW of solar PV, and to achieve national leadership in the solar value chain. To achieve these goals Beijing is allocating a total of 1.44 billion CNY (about $210 million), consisting of 980 million CNY of municipal funding, supplemented by 160 million CNY of central government funding, and 300 million CNY in district and county funding in investments across its various municipal departments.

Figure 4: Roof-top installation of solar water heaters in Beijing (photo: first author)

A central element of the development plan are the six “Golden Sunshine” solar demonstration projects which consist of a 20 MW solar PV roof-top project through which Beijing will supplement projects that qualify for the national solar roofs subsidy programme with additional financial incentives of 1CNY/watt per year until 2013. Also, a 50 MW solar PV power generation project is planned. Sustainability issues such as land use will be a major consideration, with an emphasis on the use of otherwise degraded land as well as large-scale agricultural facilities to strategically deploy solar installations. Solar campus projects will involve solar installations in 50% of all primary and secondary schools, using SWH, solar-powered lights, grid-connected PV, solar energy science classrooms and other projects, which also have the aim of educating students on the value of renewables. A SWH promotion project will provide a subsidy of 200 CNY per square meter (about 10% of the average capital cost) for the installation of SWH systems. Finally, all Beijing city parks and 30 percent of district parks will be equipped with solar lights by 2012.

For Beijing's 12th Five Year Plan (2011-2015), the goal for new and renewable energy development and utilization by 2015 is to achieve 6 percent of the city's total energy consumption, saving a total of 5.5 million tons of standard coal. The target for installed capacity of solar PV is 250 MW and for SWH collector area is 10.5 million m^2 (an addition of 4.5 million m^2 compared to 2010). Geothermal energy and heat pumps which include water source heat pumps, ground source heat pumps, and sewage source heat pumps, are set to provide heating for 50 million m^2 of floor space, twice the area compared to 2010. Biomass power generation is expected to reach a capacity of 200 MW, an increase of 170 MW. Wind power generation capacity within the Beijing municipal area or nearby is to double from 150 MW in 2010 to 300 MW in 2015 (Beijing Development and Reform Commission, 2011)

3.7 Wuxi city: Jiangsu province

Wuxi with a population 6.3 million has the target to establish a basic industrial system in line with low-carbon economy concepts by 2015. The goal is to slow carbon emission increases and decrease the carbon intensity of the industry sector by 35 percent compared to the year 2005 (for 2020, the target is 50 percent). It is planned to have 15 percent of the city's overall energy consumption generated from renewable energy sources by 2015, and 20 percent by 2020.

Specific policy goals for the promotion and up-scaled implementation of renewable energy technologies in buildings include demonstrating the implementation of hydro-thermo pump and soil-thermo pump systems. Research and demonstration of BIPV (building integrated photovoltaic) technology is being promoted with the goal of developing efficient, reliable and safe on-grid solar PV systems. By 2015, 100 MW of on-grid solar roof projects and 10 MW of on-grid BIPV projects will be installed. As in other Chinese cities, the promotion of building integrated solar thermal heating technology is another priority. By 2015, the building area with renewable energy applications is planned to constitute 15 percent of the total new built area; by 2020 this figure will increase to 25 percent.

3.8 Geothermal development: Xianyang, Shaanxi Province

Xianyang, a city of five million located in Shaanxi province, has been designated China's official geothermal city. Following a 2005 application by the city, in February 2006, the Ministry of Land Resources and the China Meteorological Administration awarded Xianyang City the title of the first "China Geothermal City".

According to the Xianyang municipal government's website[4], the proven reserves of underground thermal water in Xianyang are approximately 25 billion cubic metres. The reserve within the wider municipal area of 177 km^2 considered for development stands even higher at 37.3 billion cubic meters, equivalent to 1.97 billion tonnes of standard coal (about 57,736 PJ). The geothermal resources are at high pressure.

Xianyang started exploring and utilizing thermal energy as early as 1993. In 2005, before the city had gained the geothermal city status, only 23 geothermal wells existed and were mainly used for physical therapy, public bathing and swimming pools and household heating, According to Xianyang government, the use of geothermal heating replaced approximately 100,000 tonnes of coal each year.

According to Li (2010), at the time of writing in 2010, 40 wells had been drilled in Xianyang with depths ranging from 1500 – 3500 m, water temperatures ranging from 60 – 130°C, and well production ranging from 55 − 350 m^3/h. The main use for

[4] Xian Yang Municipal Government website on the city's geothermal development plans: http://www.xianyang.gov.cn/channel_399//75250.html

geothermal energy is now household space heating in winter, but the resources are starting to be used more comprehensively. In 2008, geothermal heating area was 2,100,000 m^2 (Li, 2010). According to Icelandic company Verkis, engaged in cooperation with Xianyang to further develop geothermal energy, the target for 2020 is 9,000,000 m^2 of floor space heated through geothermal energy (Verkis, 2009).

Under a new joint venture between Shaanxi Geothermal Energy Development and Enex China, Shaanxi Green Energy will also develop geothermal energy for household heating. The first phase of the project included the construction and operation of a geothermal district heating system, which services three colleges in the city of Xianyang, comprising 170,000 m^2 that previously burned fossil fuels for heating. The next phase, a 47 million Euro investment, is a substantial expansion of the district heating system to include a new residential area. The project is recognized to have the potential to become the largest of its kind in the world.[5]

4. Low-carbon mobility through vehicle electrification in China's cities?

Urban transport is another important sector of low-carbon urban development. Vehicle electrification in particular is more beneficial if linked to renewable energy development; ideally the two are developed together. For China, vehicle electrification offers an opportunity to avoid the lock-in to fossil-fuel based urban transport systems, but many challenges exist. The following section reviews development trends for electric two-wheelers (E2Ws), rollout plans for battery electric vehicles (BEVs), the environmental benefits and impacts associated with vehicle electrification and additional strategies for low-carbon mobility in China's cities.

4.1 Electric two-wheelers (E2Ws)

There are signs that technological leapfrogging is currently occurring in the

5 World Clean Energy Awards: http://www.cleanenergyawards.com/top-navigation/nominees-projects/nominee-detail/project/16/?cHash=72699abae7

development of China's electric vehicle (EV) industry. In particular, the development of battery technology for electric two-wheelers (E2Ws) or e-bikes is very advanced. E2Ws are a category of vehicles that includes two-wheel bikes propelled by human pedaling supplemented by electrical power from a storage battery, and scooters propelled almost solely by electricity. These two types of EV bikes have made strong advances in quality since they were first introduced in the 1990s, and the diffusion and commercialisation has accelerated dramatically since the early 2000s.

E2Ws emerged virtually from 'scratch' in the 1990s. In 2000 about 300,000 E2Ws were sold with numbers steadily increasing to 10 million in 2005 and 20 million in 2006. In 2010, about 120 million electric bikes were in use on Chinese roads.

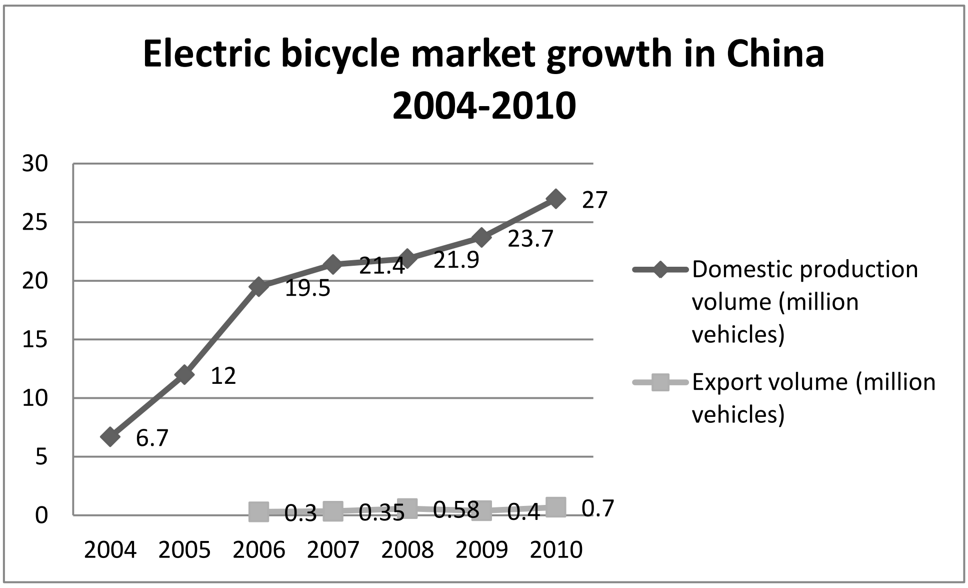

Figure 5: Electric two wheeler market growth in China 2004-2010 (Data sources: domestic production volume data from Research In China (2011); export volume data from China Bicycle Association).

The average E2W has a range of 30 to 40 km with one charge and is quickly becoming one of the dominant travel modes in China's cities – they have proven to be one of the most convenient and fastest travel options for inner city transport. E2Ws have significantly reduced impacts on air quality compared to other urban private travel options such as cars or motorcycles. Regarding CO_2 emissions, the average medium-sized e-bike uses between 3.8 and 7.6 kWh per 100 kilometers, and its use-phase emissions are in the range of 15-27 grams of CO_2 per kilometer (Asian Development Bank, 2009), depending on the emissions factor of the local electricity grid. In contrast, a passenger car in urban city traffic in China uses the equivalent of 47 to 140 kWh per 100 km, emitting 100 to 300 grams of CO_2 per kilometer (Asian Development Bank, 2009). Even compared to buses (8 to 26 kWh/100 km; 24-96 gCO_2/km) and motorcycles (21 to 42 kWh/100km; 64-128 gCO_2/km) (Asian Development Bank, 2009), the climate change impact reduction is considerable, even if electricity is generated through coal. If electricity is generated solely through renewables, the environmental impacts would be substantially less.

Aside from the environmental benefit, E2Ws are a more cost effective mobility option. In the case of Beijing, electricity for consumer use in Beijing was 0.49 CNY per kWh in 2010. Given 10,000 km traveled per year, the total electricity cost would be only between 186 CNY to 372 CNY. Compared to other options the cost is significantly lower. For instance, 10,000 km travelled by car with an average fuel consumption of 10 litre/100 km at a pump price of about 9 CNY/litre (as of March 2012) in Beijing would incur a total cost of about 9,000 CNY, between 24-48 times more expensive than traveling by E2W.

However, considering the full life-cycle environmental impacts of E2Ws, a number of drawbacks become obvious. Approximately 95% of e-bikes in the PRC are powered by lead acid batteries (Jamerson and Benjamin, 2004), although lithium-ion batteries are coming into the market. The high life-cycle lead emission rates of e-bikes are about 10–20 times as high as tailpipe emissions from leaded fuel of motor vehicles (Asian Development Bank, 2009), and the public health impacts are probably significant, although detailed studies are not available. Here lead pollution from industrial manufacturing processes of batteries stands out as a clear challenge to the environmental sustainability of this mode. Because the large batteries are replaced every 1–2 years, a medium-sized e-bike introduces 420 milligrams/km of lead into the environment during mining, smelting, and recycling stages (Asian Development Bank, 2009).

Lead emissions from the disposal stage of batteries could be reduced through appropriate recycling systems. The official recycling rate of lead in China's lead acid battery industry is currently only around 30% (Mao, Lu, et al., 2006). However, the actual recycling rate is likely to be higher, due to the informal recycling sector: some estimates are as high as 85%–100% (Asian Development Bank, 2009). Nevertheless, the situation is less than ideal with no formal incentives or take-back schemes for used batteries being so far established.

4.2 City initiatives for roll-out of electric vehicles (EVs)

In 2009, the government initiated the "Tens of Cities – Thousands of Vehicles Program" (*shi cheng qian liang gong cheng*). The intent of this programme was to stimulate electric vehicle development through large-scale pilots in ten cities that would identify and address technology and safety issues associated with electric vehicles. Ten cities were included in the initial programme rollout, but the programme was then expanded twice, so that by late 2010, 25 cities participated.[6] were:

In this programme, each city was challenged with rolling out pilots of at least 1,000 vehicles by the end of 2012. The initial focus for the programme was on government fleet vehicles with predictable driving patterns such as buses, garbage trucks, and taxis. In addition to the focus on deployment of electric vehicles for government fleets, in Shanghai, Changchun, Shenzhen, Hangzhou and Hefei private consumers were also targeted during 2010 (World Bank and PRTM, 2011).

[6] Initially the programme covered Beijing, Shenzhen, Shanghai, Jinan, Chongqing, Wuhan, Changchun, Hefei, Dalian, and Hangzhou. The program was expanded twice to include Changsha, Kunming, Nanchang, Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan and Guangzhou in the first half of 2010, and Shenyang, Chengdu, Hohhot, Nantong and Xiangfan in the second half of 2010.

The success of the program has been limited and the take-up of EVs slow. By mid-2010 only Beijing and Shanghai seemed to be on track to fulfill their targets. By the end of 2011 still only about 38 percent of their targets had been reached. The cities Hangzhou, Shenzhen and Hefei were in the lead each with 1,374, 2,011 and 2,018 new electric vehicles in operation, but remained far from their initial goals. Shenzhen in particular lagged far behind its target of 34,000 new electric vehicles in operation by the end of 2012 (ChinaEV.org, 2012).

To encourage EV adoption by private consumers, the government has also introduced purchase subsidies of CNY 60,000 per vehicle (about US$ 9000) for fully electric vehicles and CNY 50,000 per vehicle for plug-in hybrids. These subsidies are being enhanced for consumers by additional subsidies offered by cities. For example, consumers in Shenzhen will receive a substantial government subsidy – equivalent to about $18,000 USD (or 120,000 CNY) for the BYD e6 (unsubsidized price is about $56,900 (or 369,800 CNY) (BYD Energy News Center, 2011).

4.3 Chinese EV industry trends

Based on the technological developments and successful experiences of the E2W and battery industries, Chinese companies are now making strong efforts to develop fully battery electric passenger vehicles (BEVs) for urban transport. While producing automobiles clearly requires much greater technological capability and resources than producing two wheelers, several of the top E2W firms have already made the 'leapfrog' from production of E2Ws to manufacturing and selling electric three- and four-wheel fully enclosed EVs (Weinert *et al.* 2008). Yet the rollout of electric vehicles in Chinese cities faces many obstacles.

There are currently several main companies in China leading the market in electric cars: Build Your Dreams (BYD) Automotive, Wanxiang Group, Wuhan Dongfeng, Tianjin Qingquan and Anhui Qirui. BYD Automotive leads the industry and has in recent years received international attention due to their presentation of plug-in hybrid vehicles and all-electrics at international car exhibitions. BYD also garnered international media attention when US investor Warren Buffet bought a 10% share of BYD Auto for $230 million. The firm was created only in 2003 and in October 2007, BYD announced the production of a plug-in hybrid electric vehicle sedan in China. In January 2009 the company announced plans to enter the US and European markets in 2011 with a range of electric and plug-in hybrid vehicles. BYD Automotive is also developing all-electric cars with a claimed range of 200 km; however, these vehicles have not yet entered the market. According to industry reports (Chambers, 2011), tests show that currently the real battery capacity is still somewhere just under 100km. Furthermore, in 2010 BYD only sold 250 of its F3DM plug-in hybrids and 100 E6 EV models, the latter mostly to a taxi fleet partially owned by BYD in Shenzhen.

4.4 Environmental benefits and impacts of EVs

Several studies have examined the reduction of CO_2 emissions by EVs compared to other passenger car technologies. Gao, Wang and Wu (2008) compared the potential of powertrain technology improvements for private passenger vehicles to reduce carbon emissions from China's transport system. According to the study, efficiency improvements of petrol and diesel vehicles could reduce carbon emissions by about 50 percent, and moving towards vehicles using compressed natural gas or gasoline hybrids could even result in emission reductions of 55 percent. In contrast, PHEVs and EVs would only result in emissions reduction of less than 20% compared to current vehicles. Only if China's electricity mix consisted of *at least* 50 percent renewable electricity would the carbon abatement potential of PHEVs and EVs be equal to the carbon emissions reductions of other technologies. While outcomes will depend on parameters such as EV range and take-up rates, it is clear that if the electricity mix remains coal-based, EVs in China will not offer the same potential as improvements of the internal combustion engine.

Similarly, Hong et al. (2010) conclude that EVs promise little benefit in reducing CO_2 emissions currently, and only in the future would greater CO_2 reduction be expected if coal combustion technologies improve and the share of non-fossil electricity increases significantly. Because they could induce an increase in coal based electricity generation, with current technology, EVs could cause increases of SO_2 emissions by 3−10 times and a doubling of NOx emissions compared to gasoline vehicles. EVs currently would also cause~0.01 mg of mercury emissions for every kilometer driven. Whilst EVs do represent an effective contribution to problems in China such as oil insecurity and price volatility, and poor urban air quality, the flow-on environmental impacts caused by the use of subsidies to make EVs competitive with other vehicle alternatives are a significant cause for concern.

According to a World Bank study (World Bank and PRTM, 2011), there are still CO_2 emissions improvements available from plug-in EV vehicles compared to conventional vehicles, but this will vary by region. Comparing the carbon intensity of the different regional grids in China, in four Chinese regions the usage of the Nissan Leaf would result in lower emissions per km than the average internal combustion engine vehicle, as the Chinese fleet average CO_2 emissions rate for 2009 for major domestic and multinational car manufacturers was about 179 g/km.

Table 2: Illustrative carbon emissions of a Nissan Leaf EV, by region

(source: iCET Analysis cited in World Bank and PRTM, 2011)

Regional Power Grid	**Nissan Leaf CO_2 emissions g/km**
North China	261
Northeast China	260
East China	188
Central China	174
Northwest China	194
South China	155
Hainan	179

Note: Carbon emissions for the Leaf EV are not tail-pipe emissions, but upstream emissions from the fossil fuel fired power stations that supply the electricity.

4.5 Alternatives for low-carbon mobility in Chinese cities

The analysis above abstracts from a number of significant issues such as those relating to carbon embodied in vehicle manufacture, but is sufficient to show that vehicle electrification is not a complete decarbonization solution in itself. Additional issues include setting up the infrastructure of charging stations, and ensuring a transition to a low-carbon electricity generation and distribution system. The fast innovations in China's EV market and renewable electricity sector are encouraging, but appear to fall short of constituting a sustainable solution to private mobility issues in urban China. While the uptake of E2Ws offer a qualified step towards a more sustainable transport solution, the development and uptake of full battery EVs is a different story. One factor is sheer urban congestion: the rapid spread of EVs would create detrimental effects on traffic as fast as, or possibly faster than, would the spread of internal combustion engine vehicles. Creating a zero-carbon car for China's cities will not solve the wider problems of urban congestion, traffic fatalities, urban sprawl, and the paving over of arable land.

While there are currently many hurdles for China's cities to leapfrog in the urban transport sector, the potential of leapfrogging to small low-impact vehicles, especially E2Ws, exists and has merit, especially in view of the rapidly growing urban populations and automobile demand in China. It would entail a process of skipping to the most efficient, cost-effective, low-polluting commercially viable technologies available, including E2Ws, and ensuring that issues such as lead pollution are solved. Moreover, it would require smart urban design that avoids cities becoming further locked-in into car dependency. It would also require continuing development of public mass transport systems and encouragement of bicycle-based transport modes. Bike sharing facilities have become popular and exist in about 50 Chinese cities (www.publicbike.net) and there are strong health and sustainability grounds for encouraging such active transport modes (Woodcock et al., 2009).

The city of Hangzhou has set up the world's largest bike sharing system. At the end of 2009, there were 2,000 bikesharing stations with 50,000 bikes in five core districts. According to Shaheen et al. (2011), the average number of trips is 240,000 per day, and the highest daily use was 320,000 trips, with an average turnover rate of five times per bicycle per day. Stations are 200-300 meters apart in the city and 500-800 meters apart in the suburbs. The Hangzhou Bicycle Company plans to expand the bike-share system to 175,000 bikes by 2020.

5. Conclusions

The declarations and commitments of cities to becoming “low-carbon” are important first steps. However, the transition to low carbon cities is still in its infancy, and ‘leapfrogging’ in terms of urban environmental outcomes is not yet apparent, except for a few selected cases. Low-carbon development plans, indicators and methodologies need to be further developed and implemented. In most cases the cities do not have the necessary tools available to adequately measure progress towards low carbon status. Furthermore, no Chinese city is yet considering absolute reduction targets, only intensity targets (CO_2/GDP for the city).

An important obstacle for Chinese cities to achieve low-carbon development is that economic growth remains the primary focus of most urban low-carbon development plans. Progress in increasing the contribution of renewables in energy consumption in a number of progressive cities is steady and encouraging, but at around 6% in Beijing by 2015, to take an example, it is not enough to be recognised as creating a substantial impact on total carbon emissions. If other second (provincial level) and third (district level) tier Chinese cities were to follow the models of Beijing or Shanghai, which currently rank high on national “low-carbon city” lists, a critical opportunity would be lost and urban China would become locked in to high-carbon infrastructure.

Renewable energy and energy saving technologies are nevertheless already playing an important role in reducing electricity demand and related carbon emissions in many Chinese cities. In the application of solar water heating technologies Chinese cities have leapfrogged ahead compared to their international counterparts. In contrast to other renewable energy technologies, where national policies are driving development, in the case of solar water heaters support policies by local municipal governments were crucial. More recently, the application of solar PV and heat pump systems is being successfully promoted on city level, but further deployment will be necessary to reduce the share of fossil fuels in the urban electricity mix. Given the difficulties China's that solar industry is experiencing with the decline of foreign export markets, increased application and use of solar PV in Chinese cities could support healthy industry development. The difficulties mentioned in Kunming's solar development plan are likely to be representative of most other cities in China. Another question is in how far the existing successful experiences of renewable energy development in Chinese cities can be replicated by other cities.

While the adoption of electric two wheelers has positive impacts on urban air quality and carbon emissions, the effect of electric passenger vehicles (EVs) on overall carbon emissions reductions would not be significant. The large-scale introduction of EVs, which currently faces many difficulties, would certainly be a technological leapfrog, but in terms of environmental improvement, EVs will not have significant climate benefits relative to gasoline vehicles unless cities move towards decarbonising the power supply at the same time. Other environmental impacts of EVs are also cause for concern. Extending and enhancing public transport facilities and making Chinese cities more walking and cycling friendly would be likely to achieve faster emissions reductions. Bike sharing initiatives in cities such as Hangzhou have already proven very successful and could be further expanded.

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